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Bilateral Frontal Sinus Aplasia in Central Indian Adult Cadavers: Prevalence and Sex-Based Analysis

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Abstract

Background: The frontal sinus shows marked anatomical variability in size, shape, symmetry, and degree of pneumatization. Complete failure of pneumatization results in frontal sinus aplasia. Accurate recognition of this variation is relevant to endoscopic sinus surgery, anterior skull-base procedures, and forensic identification.

Objective: To determine the prevalence of bilateral frontal sinus aplasia and examine its sex-based distribution in adult cadaveric specimens from Central India.

Methods: This cross-sectional observational study examined 60 formalin-fixed adult cadaveric heads (36 male, 24 female) from an institutional anatomy collection in Central India. Each head was divided along the median sagittal plane and the frontal bone was inspected for pneumatization. When no midline cavity was seen, lateral osteotomies were extended approximately 2 cm superiorly and laterally along the supraorbital region to exclude a laterally positioned sinus. A rigid probe was used to confirm whether a mucosa-lined cavity communicated with the frontal recess. Fisher's exact test was used for the sex-based comparison, with $p < 0.05$ considered statistically significant.

Results: Among 60 cadaveric specimens, bilateral frontal sinus aplasia was identified in 4 (6.67%; 95% CI: 1.8-16.2%). Unilateral absence was observed in 3 specimens (5.00%), while bilateral presence was noted in 53 (88.33%). Bilateral aplasia occurred in 2 of 24 female specimens (8.33%) and 2 of 36 male specimens (5.56%); the difference was not statistically significant (two-sided Fisher's exact test, $p = 1.000$).

Conclusion: Bilateral frontal sinus aplasia, defined by gross anatomical absence after standardized dissection, was present in 6.67% of this Central Indian cadaveric series, without a statistically significant sex-based difference. Preoperative CT assessment remains important when frontal sinus or anterior skull-base intervention is planned. The findings should be interpreted in light of the convenience sample and absence of CT or surgical-outcome correlation.

Keywords: Frontal sinus; Aplasia; Agenesis; Cadaveric anatomy; Central India; Sex distribution; Forensic identification

1. Introduction

The paranasal sinuses are air-filled extensions of the nasal cavity situated within the frontal, ethmoid, sphenoid, and maxillary bones. The frontal sinus is particularly variable in size, shape, symmetry, and extent of pneumatization [1-3].

1.1 Embryological Development

Paranasal sinus development begins early and continues through childhood and adolescence. The frontal sinus is rudimentary or absent radiographically in early life, becomes progressively pneumatized during childhood, and may continue to enlarge into late adolescence or young adulthood [4,5]. Failure of frontal-bone pneumatization results in frontal sinus aplasia. In this article, aplasia denotes complete anatomical absence of a frontal sinus cavity; absence is used as the descriptive finding.

1.2 Surgical and Forensic Significance

Knowledge of frontal sinus aplasia is essential across several medical disciplines:

1. Functional endoscopic sinus surgery (FESS): Variations in frontal sinus and frontal recess anatomy can alter expected surgical landmarks and increase the risk of injury to the orbit or anterior skull base [6,7].
2. Neurosurgery and trauma: Pre-procedural imaging helps define frontal sinus anatomy and its relationship to the anterior skull base before procedures involving the frontal region [6,7].
3. Forensic identification: The marked interindividual variation of frontal sinus patterns has been used as a radiographic aid to personal identification [8,9].

Published prevalence estimates vary across populations and methods, while cadaveric data from Central India remain limited [10-13]. This study therefore evaluates the prevalence of bilateral frontal sinus aplasia and its sex-based distribution in adult cadaveric specimens from Central India.

2. Materials and Methods

2.1 Study Design and Specimen Selection

A cross-sectional observational study was conducted on 60 adult formalin-fixed cadaveric head specimens (36 male, 24 female) in the Department of Anatomy, Abhishek I Mishra Memorial Medical College and Research (AIMMMCR), Bhilai, District Durg, Chhattisgarh 490020, India.

A convenience sample was used. All available cadaveric head specimens in the departmental collection were screened, and specimens satisfying the eligibility criteria were included consecutively until 60 specimens were available. No random sampling or formal a priori sample-size calculation was performed; the study size reflected the number of eligible adult cadaveric specimens available for examination. This sampling approach is acknowledged as a limitation.

Inclusion criteria

Adult cadaveric heads (estimated age >20 years) with intact cranial vaults and intact midfacial skeletons were eligible. Exact donor ages were not available from the cadaveric records used for analysis; adult status was based on gross morphological assessment. Precise age-based subgroup analysis was therefore not possible.

Exclusion criteria

Specimens showing gross facial trauma, prior craniotomy/sinus surgery, severe craniofacial malformations, or destructive bone pathology.

To reduce selection bias, all available specimens meeting the eligibility criteria were included consecutively. To reduce measurement bias, dissection and classification followed a standardized protocol; ambiguous cases were re-examined by the co-investigator and resolved by consensus. Blinding to sex was not feasible during anatomical examination. Residual bias from convenience sampling is acknowledged.

2.2 Dissection Protocol

The dissection sequence was standardized for this study using gross anatomical techniques. First, each head was divided along the median sagittal plane with an oscillating bone saw to expose the nasal septum, lateral nasal wall, and midline frontal region. Second, the intersinus portion of the frontal bone was inspected for visible air cells. Third, when no cavity was seen at the midline, osteotomies were extended approximately 2 cm superiorly and laterally along the supraorbital region to exclude a laterally positioned sinus. Fourth, a rigid probe was used to determine whether a mucosa-lined cavity communicated with the frontal recess. Classification then followed the criteria below.

2.3 Classification Criteria

- Bilateral presence: Air cavities identified bilaterally within the frontal bone.
- Unilateral absence: Air cavity present on one side only; absence confirmed on the contralateral side.
- Bilateral absence (aplasia): No air cavity identified on either side despite adequate lateral dissection up to 2 cm.

2.4 Statistical Analysis

Data were tabulated using Microsoft Excel and analyzed using SPSS version 26.0. Frequency counts and percentages were calculated, and an exact binomial (Clopper-Pearson) 95% confidence interval was calculated for the overall

prevalence of bilateral aplasia. Bilateral aplasia was compared between sexes using Fisher's exact test (two-sided), with $p < 0.05$ considered statistically significant. The analysis yielded $p = 1.000$.

3. Results

Of 60 adult cadaveric specimens examined, 4 (6.67%; 95% CI: 1.8–16.2%) were classified as having bilateral frontal sinus aplasia. Unilateral absence was observed in 3 specimens (5.00%), while bilateral presence was noted in 53 specimens (88.33%).

Table 1. Distribution of frontal sinus pneumatization status by sex

Anatomical status	Male (n = 36)	Female (n = 24)	Total (N = 60)	Prevalence (%)
Bilateral presence	33 (91.67%)	20 (83.33%)	53	88.33
Unilateral absence	1 (2.78%)	2 (8.33%)	3	5.00
Bilateral absence (aplasia)	2 (5.56%)	2 (8.33%)	4	6.67
Total	36 (100%)	24 (100%)	60	100.00

Percentages are calculated within each sex column (male n = 36, female n = 24) and overall (N = 60).

3.1 Sex-Based Analysis

Bilateral aplasia was observed in 2 of 24 female specimens (8.33%) and 2 of 36 male specimens (5.56%). Fisher's exact test (two-sided) comparing bilateral absence versus all other specimens yielded $p = 1.000$. This difference was not statistically significant.

Table 2. Contingency table for Fisher's exact test

Sex	Bilateral absence	Not bilateral absence	Total
Male	2	34	36
Female	2	22	24
Total	4	56	60

Fisher's exact test, two-sided: $p = 1.000$.

4. Discussion

4.1 Comparison with Regional and Global Literature

The prevalence of bilateral frontal sinus aplasia varies across populations and study methods. Reported values include 6.25% in a US cadaveric series, 1.3% in a North Indian CT series, 2.0% in an Omani CT series, and 3.8% in a Turkish CT series [10-13].

- In a US cadaveric series of 48 specimens, Fowers et al. [10] reported bilateral frontal sinus absence in 6.25%.
- Choudhary et al. [11] reported frontal sinus aplasia in 6.6% overall in a North Indian CT study, with bilateral aplasia in 1.3% of subjects.

The present prevalence of 6.67% is close to the US cadaveric estimate reported by Fowers et al. [10] but higher than the bilateral rates reported in the cited Omani, Turkish, and North Indian radiological series [11-13]. Differences in population, sampling, age distribution, and method of ascertainment may contribute to the observed variation.

Table 3. Comparison of bilateral frontal sinus aplasia rates across populations

Population/source	Bilateral aplasia rate (%)	Method
Central India (present study)	6.67	Cadaveric
US cadaveric study (Fowers et al. [10])	6.25	Cadaveric
North Indian population (Choudhary et al. [11])	1.30	Radiological (CT)
Omani population (Al Hatmi et al. [12])	2.00	Radiological (CT)
Turkish population (Aydinlioglu et al. [13])	3.80	Radiological (CT)

Rates are shown as reported in the cited studies; study methods and sampling frames differ.

4.2 Etiological Factors

The determinants of frontal sinus pneumatization are incompletely understood. Factors proposed in the anatomical and radiological literature include:

- Craniofacial configuration: Differences in craniofacial morphology may influence the extent of frontal sinus development [5].
- Frontal bone thickness and local bony anatomy: The available diploic space may affect the extent of pneumatization [5].
- Growth-related systemic factors: Hormonal and developmental influences have also been proposed to affect frontal sinus pneumatization [5].

4.3 Surgical Implications

1. Risk of skull-base or orbital injury: During frontal recess or sinus surgery, unexpected anatomical variation can alter landmarks and increase the risk of injury to adjacent structures [6,7].
2. Frontal trephination and osteoplastic approaches: When bilateral aplasia is present, access planning should be based on preoperative imaging rather than assumed surface anatomy [6].
3. Preoperative imaging: Multiplanar CT is useful for distinguishing absent or markedly hypoplastic frontal sinuses from opacified sinuses and for defining frontal recess anatomy before intervention [6,12]. This study did not evaluate surgical outcomes; these implications are based on anatomical considerations and published literature.

4.4 Limitations

- Convenience sampling from available cadaveric specimens may not represent the general Central Indian population.
- Age estimation was based on gross morphological assessment; precise donor ages were not available for all specimens.
- The study did not include CT correlation; therefore, very small or markedly hypoplastic cavities may not have been distinguished from complete absence by gross dissection.
- Surgical outcome data were not collected; clinical recommendations are inferential.
- The non-significant sex comparison does not establish equivalence; larger samples would be needed to detect small differences.

5. Conclusion

Bilateral frontal sinus aplasia, defined by gross anatomical absence after standardized dissection, was identified in 6.67% of adult cadaveric specimens in this Central Indian series, with no statistically significant difference between males and females ($p = 1.000$). An absent or markedly hypoplastic frontal sinus may resemble complete opacification on plain radiography and can alter surgical landmarks; therefore, preoperative thin-slice CT assessment is important when intervention in the frontal recess or anterior skull base is planned. These findings should be interpreted within the limitations of convenience sampling and the absence of CT correlation.

Declarations

Ethics approval: This study was approved by the Institutional Human Ethics Committee (IHEC) of Abhishek I Mishra Memorial Medical College and Research (AIMMMCR), Bhilai, District Durg, Chhattisgarh 490020, India (Approval Reference: SSIMS/IHEC/2024/APP-048; Approval Date: 10 October 2024). The approved study involved cadaveric specimens from the institutional anatomy collection.

Consent for publication: Not applicable; no identifiable individual data are presented.

Data availability: De-identified study data are available from the corresponding author on reasonable request, subject to institutional restrictions.

Conflicts of interest: The authors declare no conflict of interest.

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Author contributions: Study conceptualization: both authors. Specimen collection and dissection: Dileep Kumar Padmakaran. Data acquisition: Dileep Kumar Padmakaran. Statistical analysis: Kommuri Kiran. Manuscript drafting: Kommuri Kiran. Critical revision: both authors. Final approval: both authors.

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